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Information Processing and Storage in Invertebrates

As outlined in greater detail in previous reports, our general aim is to isolate the neural segments responsible for the storage of information in the Limulus and then perform a series of biochemical analyses on these segments. To delineate the relevant tissue a combination of behavioral and electrophysiological techniques are being used.

One portion of the work which is nearing completion is the determination of whether the bilateral central nervous system of the horseshoe crab is a functionally "split" system, e.g., does information transduced unilaterally involve the central ganglia bilaterally? If not, it limits by 50% the amount of tissue which one must analyze. Our histology has indicated that the forebrain of the animal is bilobed and that these lobes are connected by a posterior commissure. Electrophysiological recordings indicate that the nerve activity resulting from excitation of one lateral eye does not alter the activity in the opposite lobe of the forebrain. Behavioral studies which test the cross-optic transfer of habituated responses are now almost complete and indicate that there is no transfer of information. This holds true whether one is dealing with the telson reflex or to the leg movements elicited by light. These studies should be completed in 1 - 3 months. The nerve tissue of the habituated animals is being stored for eventual analysis along with tissue from trained subjects.

The habituation studies have yielded some other interesting data. Excitation of the lateral eye at first elicits a general "escape" reaction -- all legs scramble wildly. After the first few habituation trials, we observe that only contralateral leg reflexes are elicited by the light stimulus. The second, third and fourth legs move up and out, the petal-like endings of the fifth leg close and the fifth leg folds up under the animal. As the habituation trials proceed, only the fourth and fifth legs alone move when the light is

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presented. After 100-300 habituation trials the closing reflex of the fifth leg ending as most common. There appears to be a heirarchy of responses -- different reflexes drop out at different times during the course of habituation. If we can isolate the areas of nerve tissue responsible for the control of each appendage, we should eventually be able to study biochemically various portions of the nervous system within a single crab when each portion is at a different stage of habituation.

So as to obtain as much biochemical information as possible from the stored tissue, we are extending our techniques to include lipo protein analyses as well as RNA, DNA and protein turnover assessments. The neucleic acid extraction techniques have been worked out to our satisfaction.

The planarian research is progressing satisfactorily -- we are completing the study to determine if a discriminated response survived regeneration. The results to date are positive and scattered control groups are in the final stages. Following this study we will proceed to ask whether a discrimination can be transferred via a macromolecule -- we will attempt to replicate the finding of others that enhanced learning occurs in naive subjects if they are injected with a fraction containing RNA obtained from trained animals.

Information Processing by Humans

(a) Periodicity in Task Solving

At the time of the last report we were concerned about data which did not agree with previous results. The problem was found to be in the timing apparatus and it was corrected.

Two scanning experiments have been conducted since that time. In the first, B-1, 5600 responses were obtained from each of four subjects. Preliminary power spectrum analyses indicated little periodicity, and specifically no 100-msec. periodicity. This is in direct contrast to all previous experiments of this type, in which the 100-msec. peak is the most pronounced. However, we had changed the experimental procedures greatly to permit the rapid acquisition of large numbers of responses.

The second experiment, B-2, tested the effect of one deviation in proceedure -- the time between trials. Each of five subjects first gave 1120 responses at a maximum rate (one trial every four seconds). This duplicated B-1. The subjects were then required to give 1120 responses in which they had to wait a mandatory 30 seconds between trials, approximating the time between trials of the earlier experiments where strong 100-msec. periodicities were obtained.

Currently, a complete power-spectrum analysis of B-1 is being performed by the computer. This includes editing bad data, constructing histograms, using the Wallis and Moore test for randomness on the histograms, and forming the needed autocorrelograms and power spectra of these histograms. The effect of the stimuli form is also being studied. B-2 is being readied for the same analysis.

Future experiments depend on the outcome of B-2. If periodicity in scanning turns out to be a function of the time between trials, it will be necessary to determine the specific nature of the functional dependence. Furthermore, if the difference appears at the 100-msec. peak, we will test carefully the possible hypothesis that our observed periodicity is associated with the brain alpha rhythm.

(b) If the redundancy of English is not considered, the estimate of the capacity at which humans can process spoken English is from 3 to 5 times greater than the experimentally determined capacity at which humans perform a variety of other simple tasks. Our purpose is to determine the redundancy of English on the word level, phonemic level, and distinctive feature level in order to obtain an estimate of the MINIMUM amount of information which a human must process to comprehend spoken English.

Our work consists of several distinct phases:

1. Our original data is collected on paper tape from the UPI TTS news wire. About 12,000,000 gross words have been collected to date.

2. The paper tape which is collected is edited (e.g., story headings, trailers, and other non-textual messages are deleted; numbers are converted to their written form, that is, 2 becomes two; etc.) and put onto magnetic tape. Around 8,000,000 words have now been edited and transferred onto magnetic tape. Since our program requires non-standardized operating procedure for the MSU Computer Center, we have a moderately large backlog of paper tape which should soon be put onto magnetic tape.

3. Since we are mainly concerned with the comprehension of spoken rather than written English, it is necessary to prepare a dictionary containing the phonemic transcription of each of the 30,000 or so different words which occur in our data sample. To identify and tally the English words which occur in our sample we use 8 different programs. Late last spring we discovered that the tallies of approximately 3,000,000 words which had so far been done were in error. This necessitated correction of our programs and retallying of our data tapes.

The programs have now been checked on a test sample of 25,000 words and their results agree with tallies done by another method. Computer System changes this summer necessitated some editing of our data tapes and transferring the data onto other tapes. Thus both mechanical and programming difficulties have delayed work in this area. However, we now have a dictionary of about 25,000 different words which have been phonemically translated. This will be the major part of our dictionary needed for phonemic translation (see item 4). We anticipate that program modifications which have been made will minimize earlier difficulties in tallying and permit tallying of all data tapes in a short period of time.

4. The next phase of the project is to prepare a phonemic translation of our data. A program which is based on a dictionary look-up method has been written and the main part of the program is debugged and has been checked on a known, 25,000 word sample. Subroutines which translate words with multiple pronunciations (e.g., read, the, etc.) have been written and are debugged for about half the cases. We are currently involved in the completion of debugging and testing these subroutines which will then be incorporated into the main translating program.

5. In order to calculate the redundancy at the phonemic and at the distinctive feature level it is necessary to tally the number of occurrences of each n-gram. A program to form 5 grams from the phonemic translation of the data and to do a partial tally and partial sort of the grams formed has been written, debugged, and tested. By incorporating into this program a partial sort and tally that utilizes fully the core memory of the CDC 3600 computer, we find that the output of grams is a factor of about two greater than the original data rather than a factor of 5 greater as would be found with no partial sorting and tallying. The partial sorting and tallying at this stage is not only econom-

ical of computer time and magnetic tape usage in subsequent programs, but is suggestive of the extent of the redundancy of English.

6. The CDC system SØRT routine will be used to sort the partially sorted and tallied 5-grams. A program has been written and is currently being debugged which will tally the sorted 5-grams, form the 4, 3, 2, and 1 grams (from the five grams), and tally the latter. A program is being written to convert the tallies of the 5, 4, 3, 2, and 1 grams on the phonemic level into tallies of 5, 4, 3, 2, and 1 grams at the distinctive feature level.

7. The final phase of the project is to use the tallies of the different n grams (n = 1, 2, . . . 5) in order to calculate the probability of occurrence of each n-gram and from this to calculate $\sum -p_i \log_2 p_i$ at the word, phonemic, and distinctive feature levels. In comparison with the earlier phases of the project, this last step is an easy one and will require a minimal amount of programming and computer time.

New Personnel

Dr. John I. Johnson joined the Biophysics Department (joint appointment in Psychology) in June. A small portion of his work will fall within this contract. He received his Ph.D. from Purdue University in 1957, was Assistant Professor at Marquette University 1957-60. Since that time he has been at the University of Wisconsin as a Research Fellow in Neurophysiology and during the academic year 1964-54 was at the Brain Research Unit, Department of Physiology, University of Sydney, Australia, as a Fulbright Research Scholar. Dr. Johnson's research interests include evolution of central nervous afferent systems, comparative neuroanatomy, and the relationships between behavioral specializations and interspecies variations in morphology of the central nervous system.

Publications and Manuscripts in Preparation for Publication

1. Corning, W. C. and Haight, J., "An arthropod preparation suitable for chronic electrophysiological, biochemical and behavioral study." Science, Vol. 148, p. 394-395.

2. Corning, W. C., "Retention of a discrimination following regeneration in planarians." In preparation.

3. Corning, W. C., "Test of cross-optic transfer of habituated responses in Limulus." In preparation.